LAB #1: Underwater Acoustics

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Introduction

This lab introduces students to hydrography topics such as oceanography and underwater acoustics through various questions. Questions involving salinity, sound waves, refraction, temperature, and SONAR.

Methodology

1.1) The equation used to determine the ppt is to convert a unit to another. In this case, we are converting the grams to kilograms. The equation for this would be:

Equation 1: PPT Kilogram Equation

$$\frac{gram\ unit}{\frac{gram}{kg}\ unit} = ppt\ unit$$

1.2) This equation is the rearranged version of the previous equation where we are solving for the gram unit.

2.1) This is an illustration of the question:

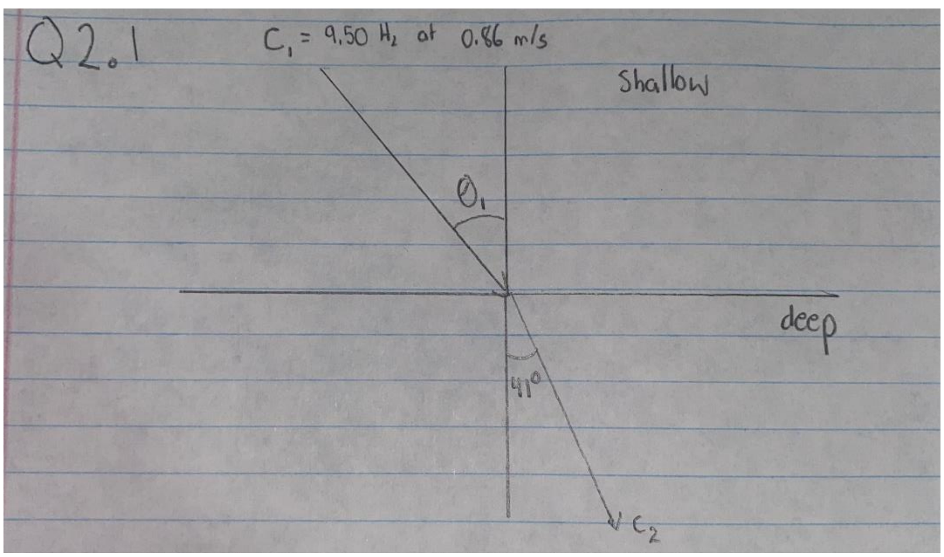

Figure 1: Illustration of Question

We will be using Snell's Law to solve this question:

Equation 2: Snell's Law

$$\frac{cos\theta(z)}{c(z)} = \frac{cos\theta_0}{c(0)}$$

2.2) An equation we can use to solve for the wavelength is the speed of sound [1]:

Equation 3: Speed of Sound Equation

$$\lambda = \frac{v}{f}$$

3) I will be using MATLAB to create these profiles. The code is attached to the appendix. I created the regions using the insert option in MATLAB Charts where I manually drew the textbox and exported it as code so I can manipulate the transparency to show the region along with the line chart.

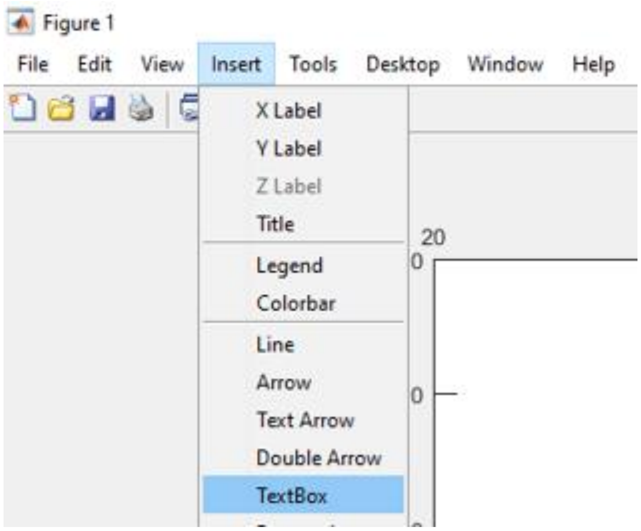

Figure 2: Drawing the Textbox

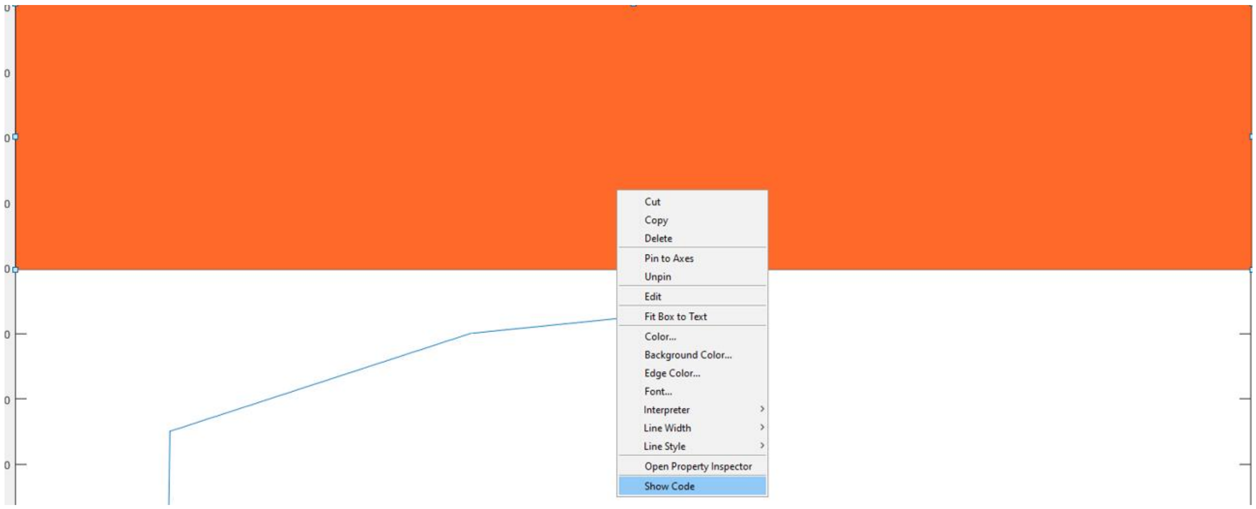

Figure 3: Exporting Textbox Code to Change Transparency

4.1) There are 3 empirical formulas that we can use to solve to compute the speed of sound:

Expression	Limits
$c = 1492.9 + 3\cdot(T-10) - 6\cdot10^{-3}\cdot(T-10)^2 - 4\cdot10^{-2}\cdot(T-18)^2 + 1.2\cdot(S-35) - 10^{-2}\cdot(T-18)\cdot(S-35) + 1.6\cdot10^{-2}\cdot D$	$-2 \le T \le 24.5$ $0 \le D \le 1000$ $30 \le S \le 42$
$c = 1449.2 + 4.6\cdot T - 5.5\cdot10^{-2}\cdot T^2 + 2.9\cdot10^{-4}\cdot T^3 + (1.34 - 10^{-2}\cdot T)\cdot(S-35) + 1.6\cdot10^{-2}\cdot D$	$0 \le T \le 35$ $0 \le D \le 1000$ $0 \le S \le 45$
$c = 1448.96 + 4.591\cdot T - 5.304\cdot10^{-2}\cdot T^2 + 2.374\cdot10^{-4}\cdot T^3 + 1.340\cdot(S-35) + 1.630\cdot10^{-2}\cdot D + 1.675\cdot10^{-7}\cdot D^2 - 1.025\cdot10^{-2}\cdot T\cdot(S-35) - 7.139\cdot10^{-13}\cdot T\cdot D^3$	$0 \le T \le 30$ $0 \le D \le 8000$ $30 \le S \le 40$

Figure 4: Empirical Formulas for the Speed of Sound

4.2) The sound profile will be developed using MATLAB

4.3) We will use the harmonic mean sound speed equation to solve this:

$$c_h(z_n) = \frac{z_n}{\sum_{i=1}^{n} \frac{1}{g_i} \ln\left(\frac{c_i}{c_{i-1}}\right)} \qquad \text{where;} \qquad g_i = \frac{c_i - c_{i-1}}{z_i - z_{i-1}}$$

Z represents depth
c represents the speed of sound

Figure 5: Harmonic Mean Sound Speed Equation

5) I used a mix of online resources [2] and class notes to answer this question.

<u>Results</u>

1.1) $\frac{25\ grams\ of\ seawater}{0.45\ kg\ of\ seawater} = 55.\bar{5}$ ppt

1.2) $salinity\ x\ seawater = 18\ ppt\ x\ 2.2\ kg = 39.6\ grams\ of\ salted\ minerals$

2.1) Plugging in our variables for Snell's law:

$$\frac{cos\theta_1}{c_1} = \frac{cos\theta_2}{c_2}$$

$$\frac{cos\theta_1}{0.86} = \frac{\cos(41°)}{c_2}$$

Rearranging for θ_1:

$$\theta_1 = \cos^{-1}(\frac{0.649}{c_2})$$

2.2) Plugging in our values that were given and derived from (2.1):

$$\lambda = \frac{0.86\cos(41°)}{9.5\cos(\theta_1)} = \frac{0.068}{\cos(\theta_1)}$$

3.1 and 3.2)

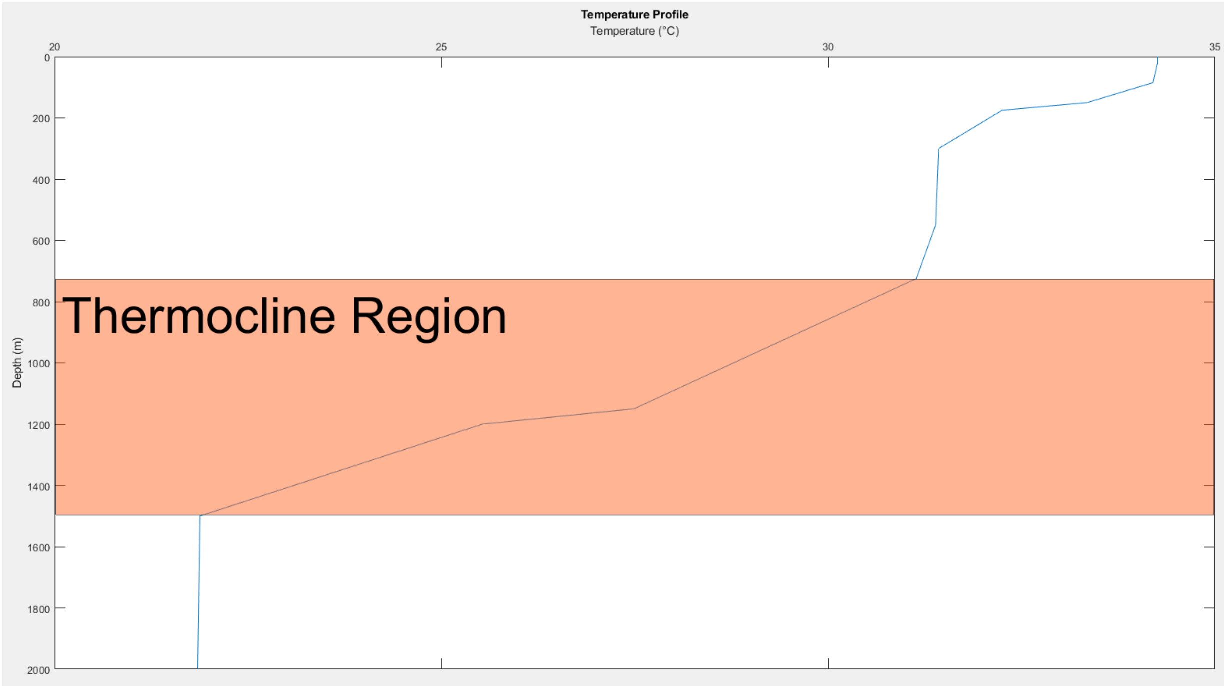

Figure 6: Temperature Profile

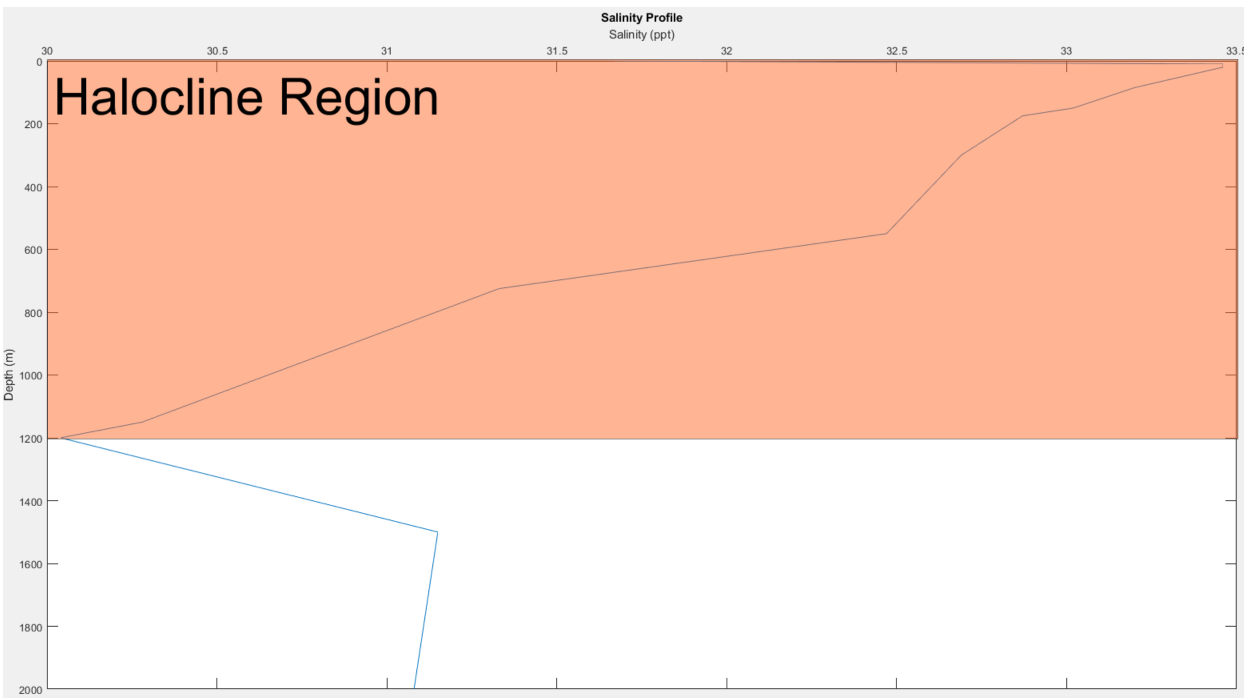

Figure 7: Salinity Profile

3.3) The thermocline region is where the temperature rapidly drops with increasing depth. Looking at [Figure 6], I considered two regions that could be the thermocline region: 0 to 250m and 775m to 1500m. Ultimately, I chose the latter because after 250m the temperature becomes constant before decreasing even more than it did initially. Also, after the 1500m, it seems the temperature becomes constant as there is no sign of temperature change for 500m, which clears up the selection of the 2 possible thermocline regions.

The halocline region is where the salinity experiences a rapid change typically seen in depths closer to the surface as lower salinity water (which has a lower density) floats on top of higher salinity water (high density). This region seems a bit more obvious than the thermocline region but overall is changing rapidly. The reason I chose to select 0m to 1200m rather than the entire 2000m is that I think 0m to 1200m has a greater rate of change than the entire 2000m. I chose to cut it off at 1200m instead of 1500m because the rate of change between 1150m to 1200m is 0.0048ppt/m whereas between 1200m to 1500m it is 0.0037ppt/m. The rate of change seemed to slow down, and I decided to cut it off there.

4.1) I tabulated the data corresponding to the empirical formula limits. Empirical formula 1 was not used at all. Equation 2 was used for the first 9 values and equation 3 was used for the rest.

Table 1: Tabulated Data for Speed of Sound

Temperature (°C)	Salinity (ppt)	Depth (m)	Equation	Speed (m/s)
34.26	31.67	0	2	1550.58
34.26	33.46	10	2	1552.53
34.26	33.46	20	2	1552.69
34.2	33.2	85	2	1553.35
33.35	33.02	150	2	1552.60
32.35	32.87	175	2	1550.71
31.43	32.69	300	2	1550.88
31.39	32.47	550	2	1554.57
31.14	31.33	725	2	1555.69
27.49	30.28	1150	3	1553.96
25.53	30.04	1200	3	1549.97
21.88	31.15	1500	3	1546.98
21.85	31.08	2000	3	1555.20

4.2)

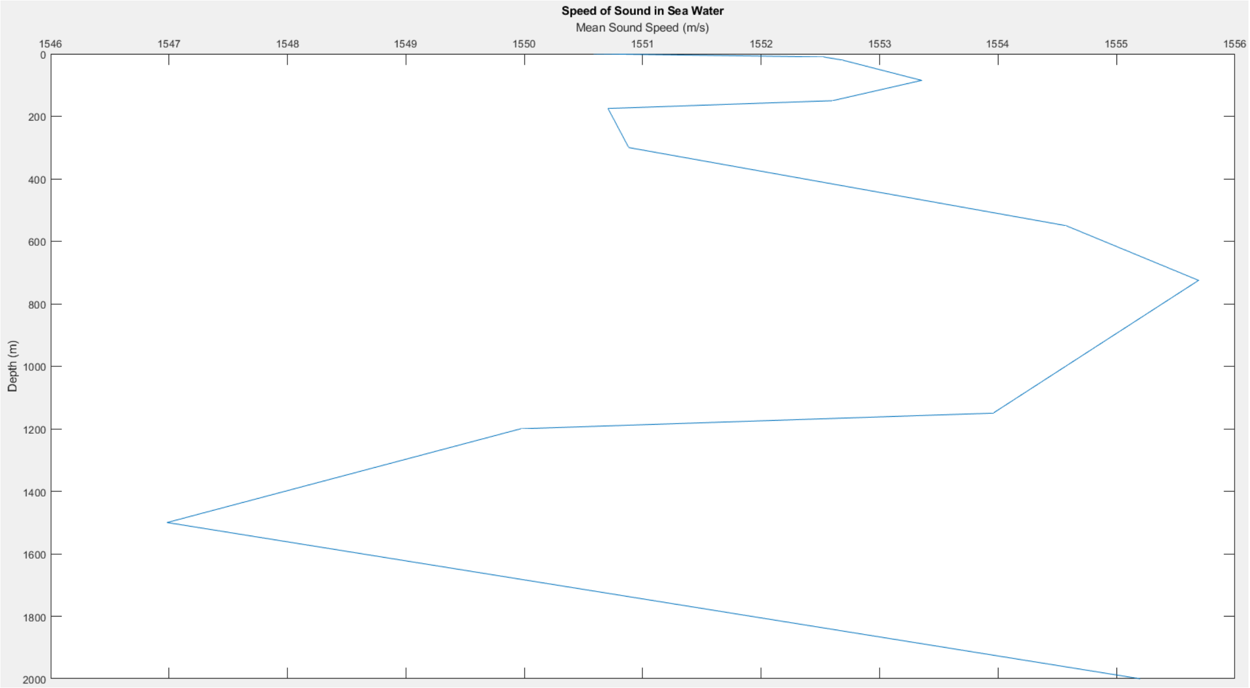

Figure 8: Sound Speed Profile

4.3) To compute the mean sound, we cannot use a mean function as the layers of the depth are represented differently. z_n in this equation is 2000m as it is the deepest layer and represents the last number of n (13). I have computed the sum through MATLAB.

$$c_h(2000) = 1552.19\ m/s$$

5) The SONAR Equation is as follows:

Equation 4: SONAR Equation

EE = SL – 2TL – (NL-DI) + BS – DT

Source Level (SL):

Refers to the acoustic signal intensity emitted from a sound signal. It is measured 1 meter from the centre of the transmitter.

Transmission Loss (TL):

Refers to the loss of signal intensity as the wave spreads and is absorbed depending on the properties of the sea water. The wave spread can be represented with the geometry of a cone where the increase of its area results in a decrease in intensity:

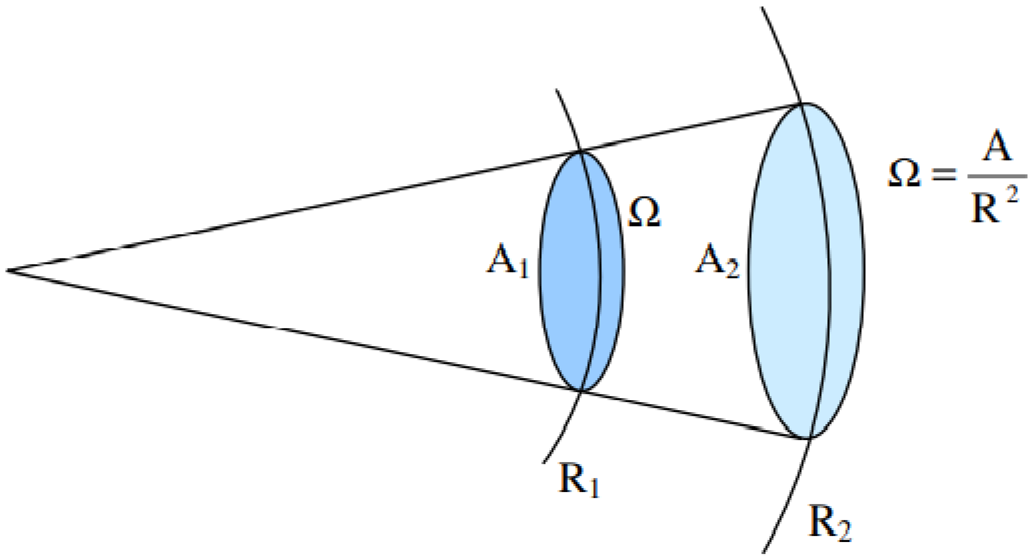

Figure 9: Spreading Loss due to Beam Geometry [2]

$$\text{Where } \Pi \text{ represents the power (intensity} * \text{area)}$$

$$\Pi = \mathrm{I1} \cdot \mathrm{A1} = \mathrm{I2} \cdot \mathrm{A2}$$

$$\text{where } A_1 = \Omega \cdot R_1^2 \text{ and } A_2 = \Omega \cdot R_2^2, \text{being } \Omega \text{ the solid angle}$$

Noise Level (NL):

Refers to the noise picked up by equipment which can be found in two forms: environmental spectral noise level and transducer bandwidth during reception. Environmental spectral noise refers to noise that can be heard in the water like seismic activity, waves, rain, organisms, thermal noise. Transducer bandwidth refers to the noise generated from the equipment itself.

Directivity Index (DI):

Refers to the acoustic signal waves that is returned from the seafloor. These waves can experience as a reflectance as it meets and penetrates sediment. This can be used to deduce the seafloor properties based off the beam angle, sound speed, and its backscatter strength corrected from absorption.

Backscatter Strength (BS):

Refers to the acoustic signal waves that is reflected from the seafloor. The backscattered signal is used to correct for the absorption and the scattering due to the seafloor. It is based off the incident angle of the transducer.

Detection Threshold (DT):

Refers to the system that establishes the sensitivity of the echo sounder by determining the lowest level which the system can detect echoes.

Resources

Armenakis, C. (2022). Lecture: Introduction to Hydrography and Underwater Acoustics Unit 1. ESSE 4650 Hydrography. Toronto, Ontario, Canada: York University

[1] How To Calculate Wavelength. (2020, February 25). Retrieved January 19, 2022, from http://forbiddenpc.com/calculate-wavelength/

[2] International Hydrographic Bureau (2005). *Manual on Hydrography*. Monaco. Retrieved January 20, 2022.

MATLAB Code

```
% Q3
temp = [34.26 34.26 34.26 34.2 33.35 32.25 31.43 31.39 ...
    31.14 27.49 25.53 21.88 21.85];

sal = [31.67 33.46 33.46 33.2 33.02 32.87 32.69 32.47 ...
    31.33 30.28 30.04 31.15 31.08];

dep = [0 10 20 85 150 175 300 550 725 1150 1200 1500 2000];

figure(1)
plot(temp, dep)
set(gca, 'YDir','reverse')
set(gca, 'XAxisLocation', 'top')
title('Temperature Profile')
xlabel('Temperature (°C)')
ylabel('Depth (m)')

annotation(figure(1),'textbox',...
    [0.131208333333333 0.315680166147456 0.773479166666667 0.313603322949117],...
    'String',{'Thermocline Region'},...
    'FontSize',48,...
    'FitBoxToText','off',...
    'BackgroundColor',[1 0.411764705882353 0.16078431372549], ...
    'FaceAlpha', 0.5);

figure(2)
plot(sal, dep)
```

```
set(gca, 'YDir','reverse')
set(gca, 'XAxisLocation', 'top')
title('Salinity Profile')
xlabel('Salinity (ppt)')
ylabel('Depth (m)')

annotation(figure(2),'textbox',...
    [0.130729166666667 0.435098650051921 0.775520833333333 0.49221183800623],...
    'String',{'Halocline Region'},...
    'FontSize',48,...
    'FitBoxToText','off',...
    'BackgroundColor',[1 0.411764705882353 0.16078431372549], ...
    'FaceAlpha', 0.5);


% Q4
x = [];
for i = 1:13
    if temp(i) >= -2 && temp(i) <= 24.5 && dep(i) >= 0 && dep(i) <= 1000 && sal(i) >=
30 && sal(i) <= 42
        x(1,i) = 1492.9 + 3*(temp(i)-10) - 0.006*(temp(i)-10)^2 - 0.04*(temp(i)-18)^2
...
            + 1.2*(sal(i)-35) - 0.01*(temp(i)-18)*(sal(i)-35) + 0.016*dep(i);

        x(2,i) = 1;

    elseif temp(i) >= 0 && temp(i) <= 35 && dep(i) >= 0 && dep(i) <= 1000 && sal(i) >=
0 && sal(i) <= 45
        x(1,i) = 1449.2 + 4.6*temp(i) - 0.055*temp(i)^2 + 0.00029*temp(i)^3 + ...
            (1.34 - 0.01*temp(i))*(sal(i)-35) + 0.016*dep(i);

        x(2,i) = 2;

    elseif temp(i) >= 0 && temp(i) <= 30 && dep(i) >= 0 && dep(i) <= 8000 && sal(i) >=
30 && sal(i) <= 40
        x(1,i) = 1448.96 + 4.591*temp(i) - 0.05304*temp(i)^2 + 0.0002374*temp(i)^3 +
...
            1.34*(sal(i)-35) + 0.0163*dep(i) + 1.675*10^-7*dep(i)^2 - ...
            0.01025*temp(i)*(sal(i)-35) - 7.139*10^-13*temp(i)*dep(i)^3;

        x(2,i) = 3;
    end
end

figure(3)
plot(x(1,:), dep)
set(gca, 'YDir','reverse')
set(gca, 'XAxisLocation', 'top')
title('Speed of Sound in Sea Water')
xlabel('Mean Sound Speed (m/s)')
ylabel('Depth (m)')

c = x(1,:);

gi = [];
ci = [];
for i = 1:12
    gi(i) = (c(i+1)-c(i)) / (dep(i+1)-dep(i));
    ci(i) = c(i+1) / c(i);

    bot(i) = (1/gi(i))*log(ci(i));
end
```

```
ch = 2000 / sum(bot);
```